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Environ economic analysis of various types of photovoltaic technologies integrated with greenhouse solar drying system

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ABSTRACT

In present communication, greenhouse solar dryer under forced mode integrated with different types of photovoltaic (PV) technologies have been proposed. Further, various parameters have been evaluated on environmental point of view for different weather condition of New Delhi, India. For numerical analysis, radiation data and ambient air temperature have been taken from IMD (Indian Meteorological Department), Pune. Further, different parameter such as crop temperature, greenhouse temperature and cell temperature have been calculated with experimental validation by the help of MATLAB 2013a. Overall (equivalent) thermal energy found to be 1838.16, 1740.98, 1351.22, 1472.12 and 1527.86 kWh for c-Si, p-Si, a-Si, CdTe and CIGS PV technologies integrated with drying system respectively on yearly basis. Further, embodied energy, energy payback time, CO_2 mitigation and carbon credit earn through different PV drying system have also been calculated. It was found that payback time for c-Si, p-Si, a-Si, CdTe and CIGS system are 1.13, 0.98, 0.93, 0.82, and 0.39 years respectively on the basis of equivalent thermal energy.

1. Introduction

The expansion of cleaner and renewable energy sources are necessary so that fossil fuel dependency and global warming can reduce. Solar Dryers are considered as one of the clean technologies and optimal use of these can diminish the use of fossil fuels (non-renewable energy), and can play a vital role in the world's future. Solar dryer used for drying of forest products is one of the most suited and cost effective method for utilization of solar energy because with the help of solar drying, forest residues can be converted into profitable biomass as biofuel (Perea-Moreno et al., 2016). Also, solar drying is an oldest and economical food protection techniques. Farmers are using open sun drying since olden time for drying of fruits, fish, plants, meat, seeds, wood, and forest products or other agricultural for preservation (Ekechukwu, 1999). Open sun drying have some drawbacks namely, quality degradation caused by microbiological or biochemical reactions, insect infestation, decolouration, absence of facility to control the solar drying process. In recent time, some agricultural products have also been gaining importance like pineapple, apples, banana, mango, and pears (Guine and Castro, 2002). Solar dryers came into existence to improve the quality of dried crops. Solar drying system may be utilized in two ways namely, forced mode and natural mode. Pawar et al. (1995) and Barnwal and Tiwari (2008) worked on custard powder and grape drying were proved that forced mode of drying is superior to natural mode with reference to governing drying parameters.

Kabeel and Abdelgaied (2016) investigated the solar dryer unit combined with solar air collector, rotary desiccant wheel and drying unit. Theoretical models have been developed for solar collector as well as desiccant wheel and validated with experimental data. From the experimental results, it was found that the temperature of drying air improved from 65 °C to 82 °C and the humidity ratio reduced from 15 to 8.8 (g water)/(kg dry air) for same condition in comparison to the solar drying units without using a desiccant wheel. Adnane et al. (2016) dried henna (Lawsonia alba, syn. Lawsonia inermis Linn.) by using the best nominated flat plate collector (FPC) and studied the drying behaviour for this. The results shows that drying time with 0.024 kg/s mass flow rate of air is smaller than those with 0.012 and 0.036 kg/s.

Various types of solar operated air heaters and drying systems have been investigated in the past for the effectual deployment of solar energy (Sami et al., 2011). Solar air FPCs are widely used over

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the years due to its simplicity in design with a nominal use of materials, low capital cost and easy in handling (Kalogirou, 2004). Ramírez et al. (2015) compared the carbon and water footprint of the obtainable dried tomato value chain form greenhouse and the conventional process. Through monthly experimental results, it was found that the water footprint was decreased from 91 to 51.1 L kg^{-1} with a standard deviation from 53.2 to 12.4 L kg^{-1}. It is also observed that the carbon footprint was decreased from 40.2 to 11 kg kg-1 with a standard deviation from 23.9 to 11.4 kg carbon dioxide kg^{-1}. Mishra and Tiwari (2013) made an attempt to calculate and compare the energy matrices of a hybrid PVT (photovoltaic thermal) water collector with five dissimilar types of PV modules namely, c-Si, p-Si, a-Si (thin film), CdTe and CIGS and found that c-Si PV module is best alternative for production of electrical power. Agrawal and Tiwari (2013) investigated that the solar air collector coupled with the glazed PV module gives a higher capability for energy saving in comparison to PV module. Agrawal and Tiwari (2012) investigated energy matrices and concluded that if the price of energy in the production of parts of the air collector coupled with PV module included, the efficiency was decreased and payback was increased by approximately a factor of four. Tan et al. (2017) was established an indicator framework for the assessment of low carbon cities (LCC) from the perspectives of social and living, economic, carbon and environment, energy pattern, solid waste, urban mobility and Water. Song et al. (2012) concluded that solar assisted drying system can reduce the carbon emission for sustainable development which is necessity of society. Coskun et al. (2011) analysed global solar radiation distribution for PV panel and thermal collector systems which is useful in performance analysis of PV systems. Akyuz et al. (2012) developed approach for estimation of photovoltaic exergy efficiency. Tiwari et al. (2016) investigated a PVT greenhouse solar dryer. In their analysis, overall (equivalent) thermal energy has been calculated and found to be 1.92 kWh by theoretical model and 2.03 kWh experimentally. Tiwari and Tiwari (2016a) analysed a PVT greenhouse solar drying system under forced mode. On the basis of yearly analysis, thermal energy, electrical energy and overall (equivalent) thermal energy found to be 1182.19 kWh, 191.53 kWh and 1686.22 kWh respectively.

In previous studies, Tiwari and Tiwari (2016b) has done the energy analysis for PV integrated drying system in which the entire roof of the drying system is made of c-Si PV module with an additional glazing added below the PV module. As a result of extra glazing and PV module, the direct radiation reduced to increase the product quality in terms of colour. Present study is an investigation to find most suitable PV technology in terms of energy production (thermal and electrical), payback time and carbon credit earned for solar drying system among c-Si, p-Si, a-Si, CdTe and CIGS. This paper may helpful for researchers to decide which PV technology is best for greenhouse dryer roof in reference of above mentioned parameters. PV integrated greenhouse dryer is suitable for country side parts where grid connectivity for electricity is not available. Present system is not only helps in drying but also can serve daily electricity needs for villagers. Calculation have been made for different climatic conditions includes Type a, Type b, Type c, Type d which can be defined as the ratio of daily diffuse to daily global radiation are less than or equal to 0.25, between 0.25 and 0.50, between 0.50 and 0.75 and greater than or equal to 0.75 respectively (Dubey et al., 2009).

2. Experimental setup

Present experimental setup (greenhouse dryer) under forced mode has been shown in Fig. 1. System comprises of 3 semi-transparent PV module (1 m × 0.6 m each) made of c-Si, D.C. fan (12 V, 1 A) and a drying space. PV module helps to run the drying system under forced mode by running DC fan. It also provide shading effect to avoid decolouration of crop and excess power to store. Present drying system has two door at north side to charge the crop. Calibrated copper-constantan thermocouples connected through digital temperature indicator (least count: 0.1 °C) was used to measure the crop temperature. Solar cell temperature, ambient air temperature and greenhouse room air temperature were measured through mercury thermometers (least count: 0.2 °C). Relative humidity inside greenhouse has been measured with the help of digital humidity meter (model: Lutron HT-3003; least count: 0.1%) and solar radiation measured through solarimeter (least count: 1 W). A digital balance (model: Virgo; capacity: 10 kg, least count: 1 g) and an electronic digital anemometer (model: Lutron AM-4201, range: 0.2–30.0 m/s; least count: 0.1 m/s) were used to weigh the samples crop at hourly intervals during drying and wind speed respectively.

2.1. Thermal modelling

Assumptions considered for thermal modelling (Singh and Tiwari, 2016):

i. Heat capacity of solar cell, metal and glass have been neglected,
ii. Thin layer drying has been considered,
iii. Single tray has been considered in thermal modelling,
iv. Quasi-steady state condition has been considered.

Energy balance equation on PV module (Tiwari and Tiwari, 2016a).

Incident solar radiation on semi-transparent PV module can be utilize in two ways, namely thermal energy and electrical energy. One part of thermal energy can be transfer to the drying chamber through the bottom of PV module and rest part is lost in environment through top loss. The energy balance can be seen in Equation (1)

$$\alpha_c \tau_g \beta_c I_t A_m = U_{tca}(T_c - T_a)A_m + U_{bcr}(T_c - T_r)A_m + \tau_g \beta_c \eta_c I_t A_m \tag{1}$$

Temperature dependent solar cell efficiency can be given as (Evans, 1981)

$$\eta_c = \eta_o(1 - \beta_o(T_c - T_o)) \tag{2}$$

Energy balance equation for crop (Tiwari and Tiwari, 2016a).

Solar energy is coming to crop in three ways namely, indirect energy from semi-transparent PV module as a bottom loss, direct radiation from four walls of dryer and direct radiation coming from non-packing portion of the PV module. Available thermal energy is used to raise the crop temperature and drying chamber temperature. The energy balance can be seen in Equation (3)

$$\begin{aligned}&\alpha_{cr}\tau_g^2\tau_g'(1-\beta_c)I_t A_c + \alpha_{cr}\tau_g A_c \sum I(i)\\&\quad = M_{cr}C_{cr}\frac{dT_{cr}}{dt} + h_{cr}(T_{cr} - T_r)A_c\end{aligned} \tag{3}$$

Energy balance equation for greenhouse room (Tiwari and Tiwari, 2016a).

The thermal energy lost to greenhouse chamber is equal heat carried away by the air and heat loss through the greenhouse chamber wall. So the energy balance equation for greenhouse chamber can be seen in Equation (4)